# Continuum and molecular line surveys: the need of both to understand molecular cloud and star formation


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and… JCMT, Mopra, SMA, PdBure, BLAST, STO,….

*Background image: **Spitzer Legacy survey of Cygnus X** (Hora et al.)*

# Outline

1. **Introduction**

   Turbulent cloud structure and star formation

   Observations and models

2. **Spatial cloud structure**

   - self-similar or characteristic size scales ?
   - filaments… the link between cloud structure and star formation ?

3. **Density structure of molecular clouds**

   - Probability Density Functions (PDFs)

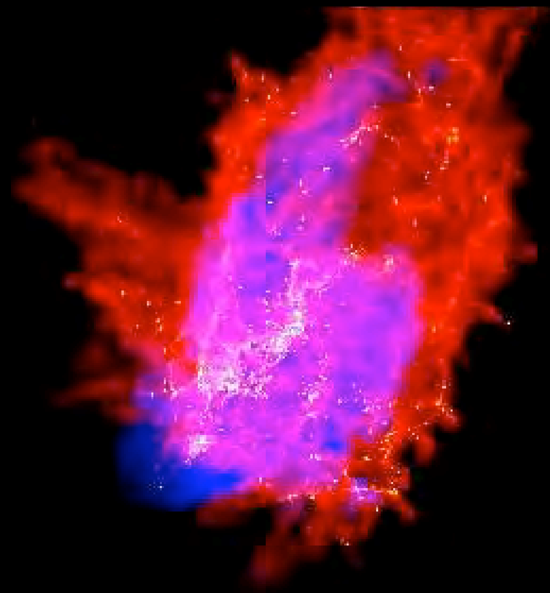
# Observations


Herschel Gould Belt Program (André et al. 2010), Men'shchikov et al. 2010


Herschel HOBYS Program (Motte et al. 2010), Schneider et al. 2010

# Models

Isothermal supersonic turbulence (Padoan et al. 2001), also Klessen et al.

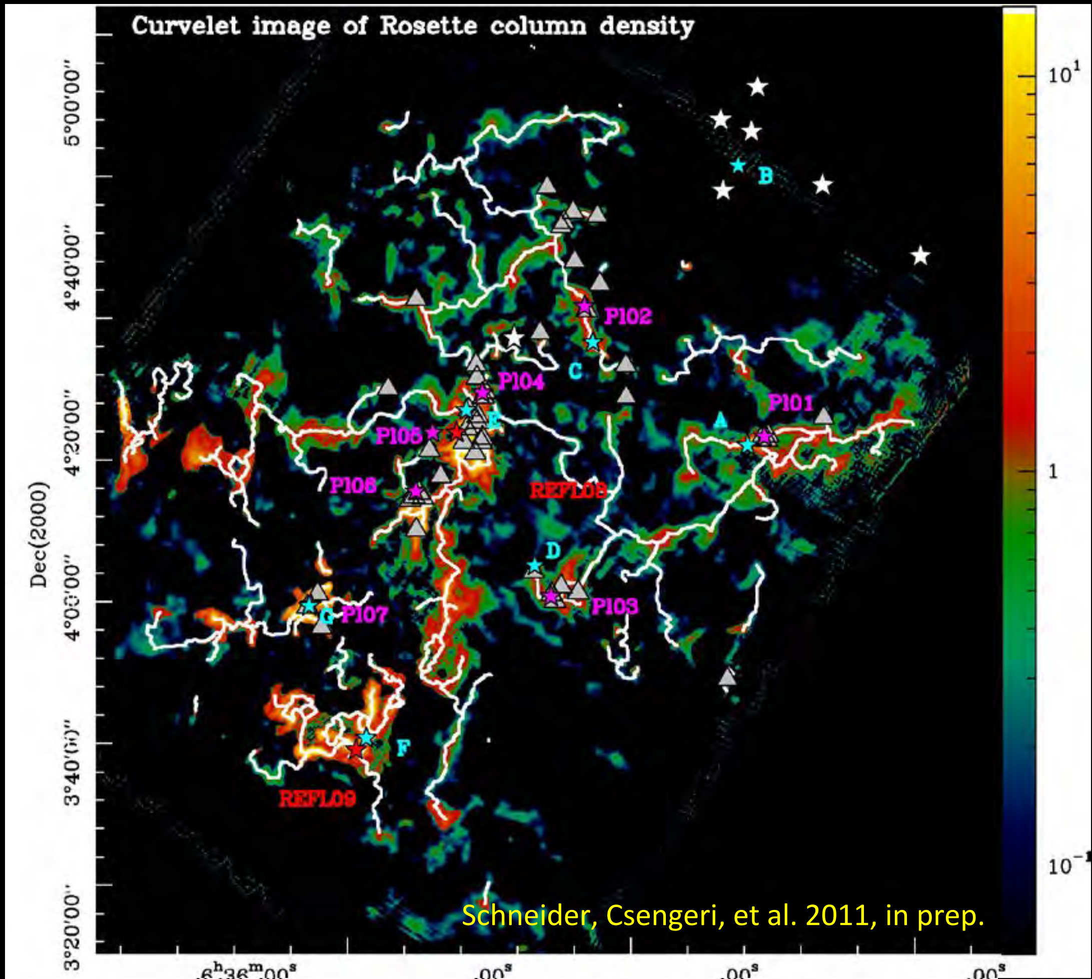


SPH model with self-gravity and ionizing radiation (Dale & Bonnell 2011)

# HOBYS:
# *Herschel* imaging surveys of OB Young Stellar objects

More HOBYS results in talk by M. Hennemann

F. Motte, A. Zavagno, S. Bontemps + HOBYS **KP Consortium**




Rosette Molecular Cloud (*Herschel* 70, 160, 250 µm)

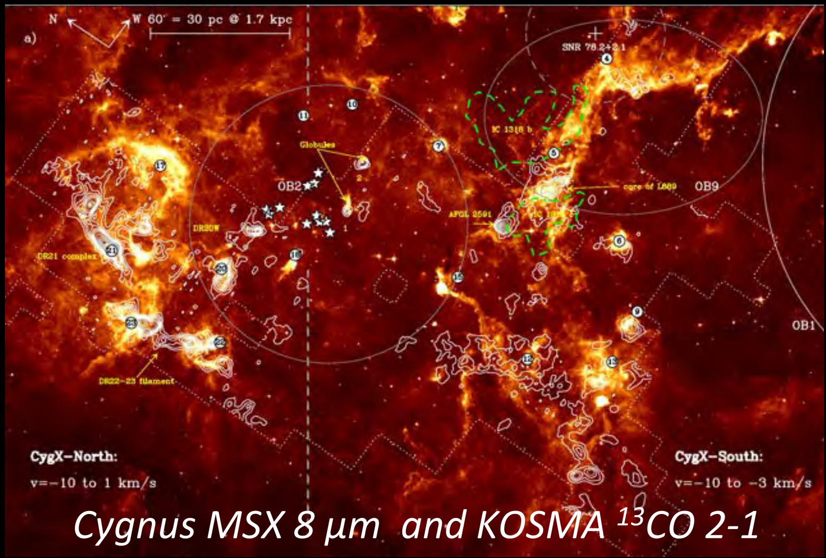
- Curvelet (Starck et al. 2003) analysis reveals the structure.
- DisPErse (Sousbie 2011) traces the filaments.

**(Massive) clusters form at the *junctions* of filaments.**

***Photoionization* has little impact on star-formation.**

# Observations

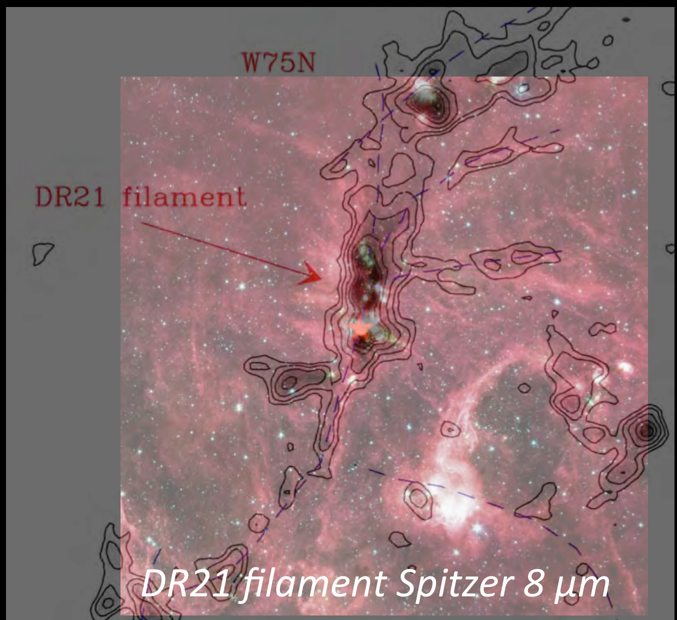
# Models




*Cygnus MSX 8 µm and KOSMA $^{13}CO$ 2-1*

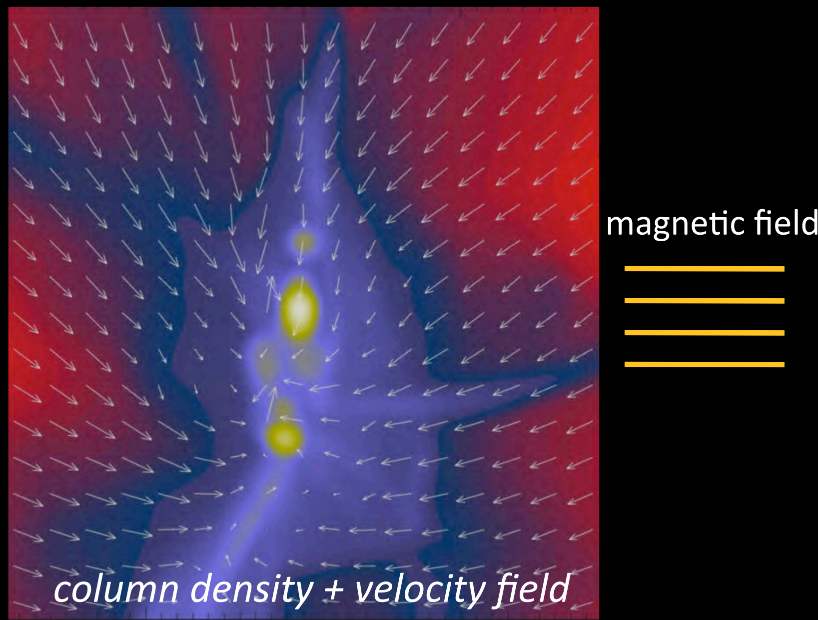
Schneider, Bontemps, Simon et al. 2006

Hydrodynamic model with radiation (Bate 2009)




*DR21 filament Spitzer 8 µm*

Spitzer Legacy survey Cygnus X (Hora et al. 2009)
Schneider et al. 2010, Csengeri et al. 2010, 2011




*column density + velocity field*

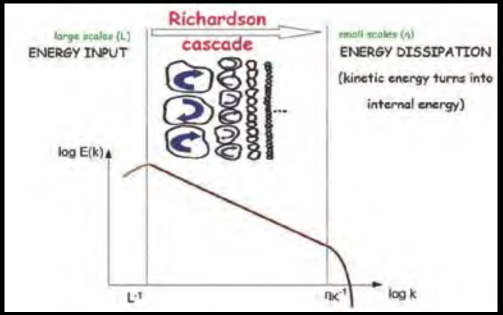
Magneto-hydrodynamic model of DR21 filament (Hennebelle et al.)

# Method to analyse molecular cloud structure: **Δ-Variance**

Stutzki et al. 1998; Ossenkopf, Krips & Stutzki 2008 a,b

Studies: Rowles & Froebich 2011, Schneider et al. 2011, Federrath et al. 2009,2010, Ossenkopf et al. 2001,2006, Sun et al. 2006, Simon et al. 2000, Plume et al. 2000, Bensch et al. 1999, Zielinsky & Stutzki 1999....

For a 2D-image, assuming a *turbulent cascade,* the power spectrum is




$P(k) \sim |k|^{-\beta}$ k= spatial frequency

and the **Δ-variance**

$\boxed{\sigma^2 \sim L^{\beta-2}}$ L= lag (in arcmin or pc)

$\sigma^2$ *measures the amount of structure on a scale* L by filtering the map with a wavelet function

→ a power-law fit gives the slope β.

# Molecular cloud structure: Δ-Variance on near-IR extinction maps

low-mass SF regions

## Geometry

length/width of **filaments** caused by energy injection of

**SNR shells:** scales of a ***few*** to ***a few 10 parsecs***

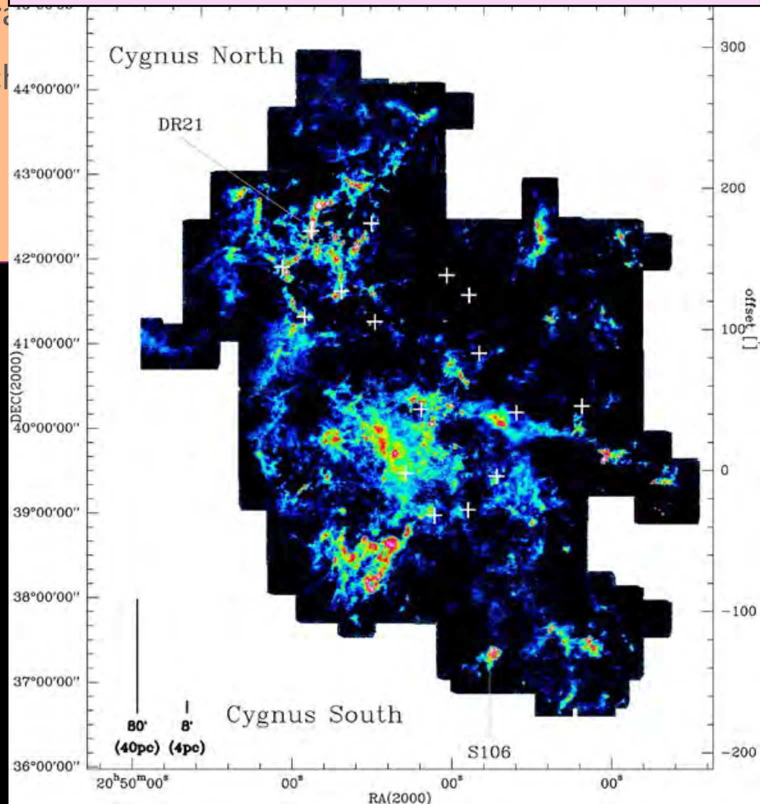
**HII-regions:** scales of ***several parsecs***

**outflows:** small scales ***< 0.3 pc*** (Nakamura

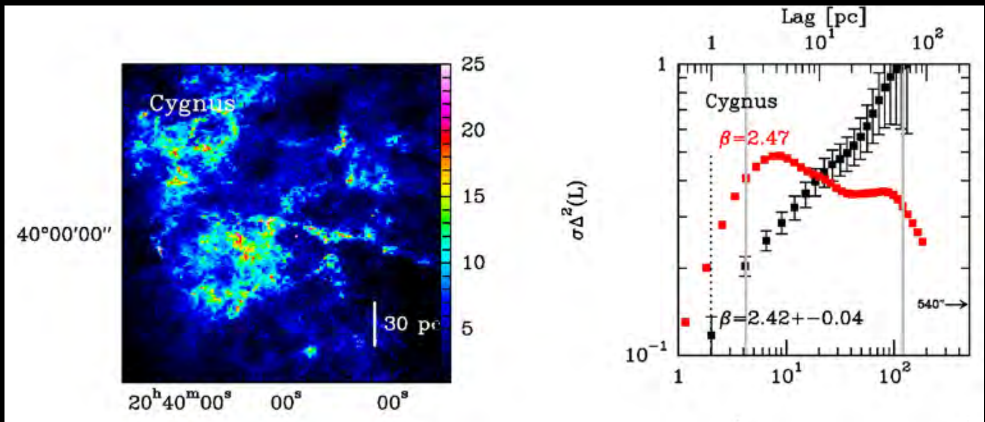
**sonic scale:** smaller scales ***(0.1-0.5 pc)*** (Sch

(turbulence becomes subsonic)

FCRAO $^{13}$CO 1-0 35 deg$^2$
(Schneider et al. 2011,Simon et al.)




high-mass SF regions

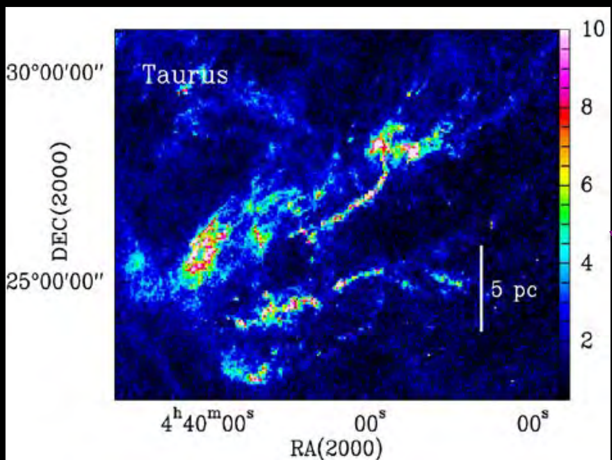


# Probability density functions (PDFs)

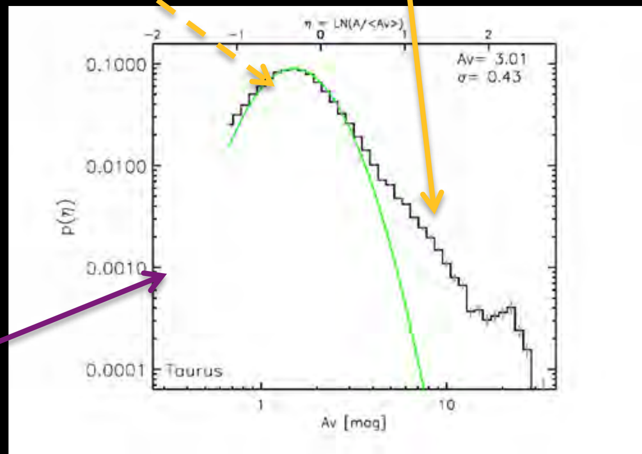
- Statistical tool to describe the probability of a volume dV to have a density between ρ and ρ+dρ (Padoan 1997, Federrath et al. 2008…)
  To first order, the 2D-column density can be used (Lombari, Alves, Lada 2006; Kainulainen et al. 2009, 2010; Froebrich & Rowles 2010)
- The distribution has a **log-normal** form for many classes of clouds (Tassis et al. 2010) , including isothermal turbulent gas, but deviates from this form in case of **self-gravity**.

$$p_s\,\mathrm{d}s = \frac{1}{\sqrt{2\pi\sigma_s^2}}\exp\left[-\frac{(s-\langle s\rangle)^2}{2\sigma_s^2}\right]\mathrm{d}s.$$

*"high-density power-law tails"* (e.g. Kainulainen et al. 2009, Ballesteros-Paredes et al. 2011)




Av-map of Taurus



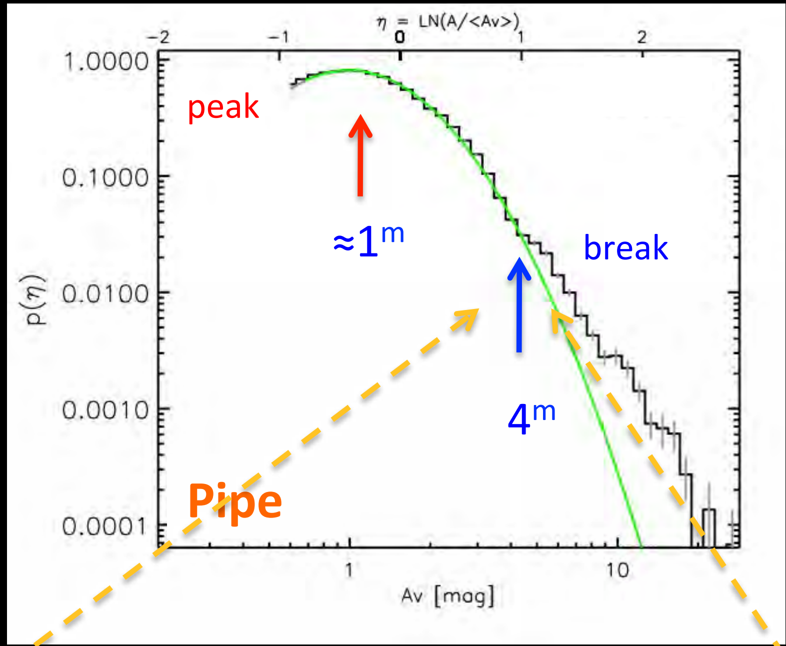

PDF of Taurus
(Csengeri, Schneider, Ossenkopf et al., in prep.)

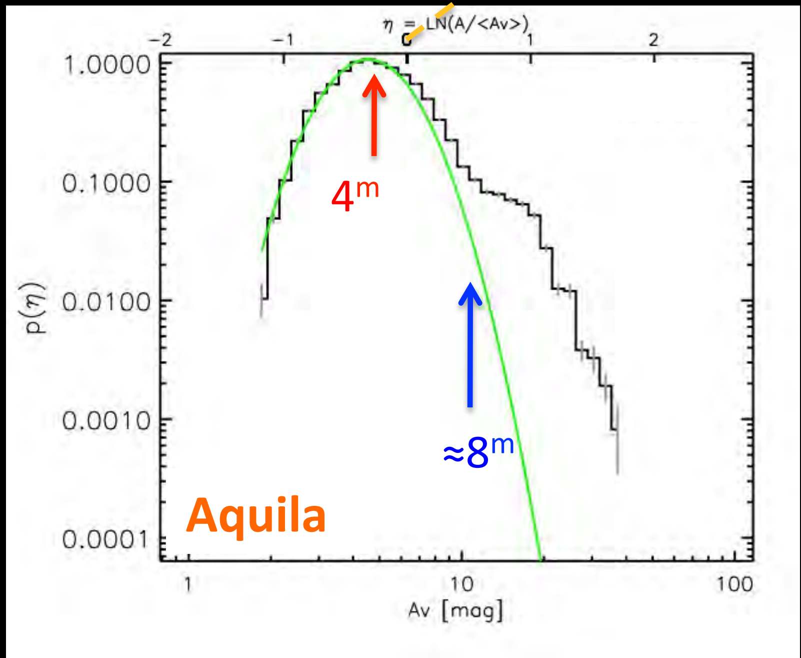
## PDFs from extinction maps

(Lombardi et al. 2006;
Kainulainen et al. 2009,2010;
Csengeri, Schneider, Ossenkopf et al.)

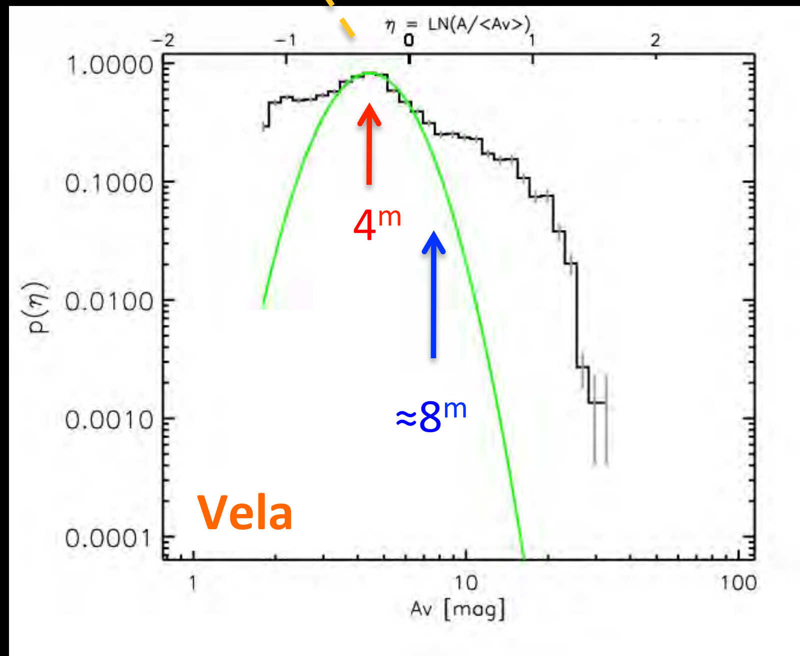
low-mass SF
molecular cloud

Kainulainen et al. 2010:
Pressure ?
Phase transition between dense clumps and interclump medium

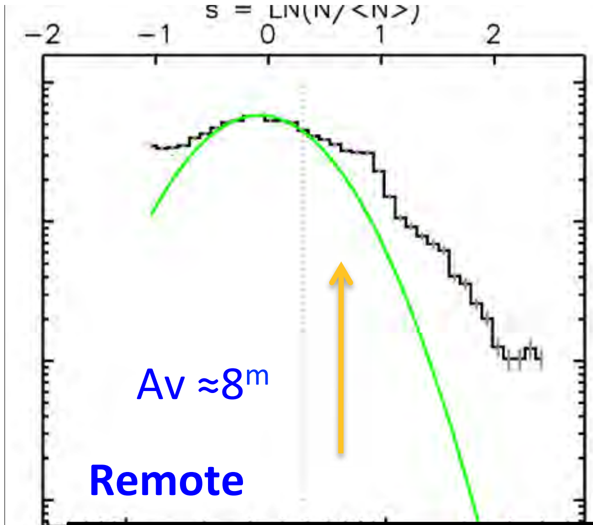


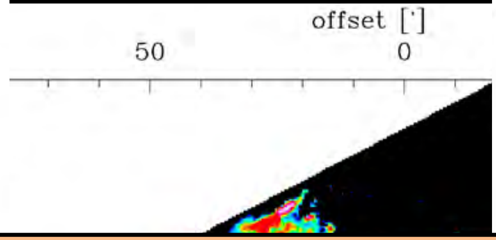

intermediate-mass SF molecular cloud

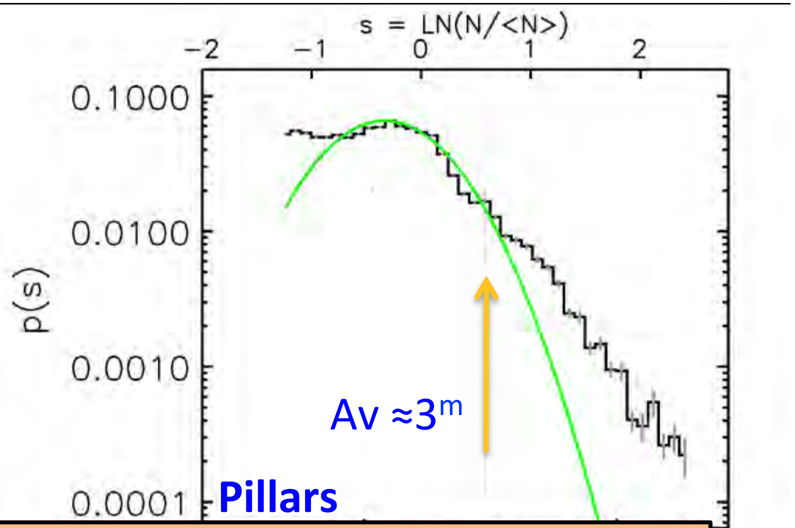



high-mass SF molecular cloud

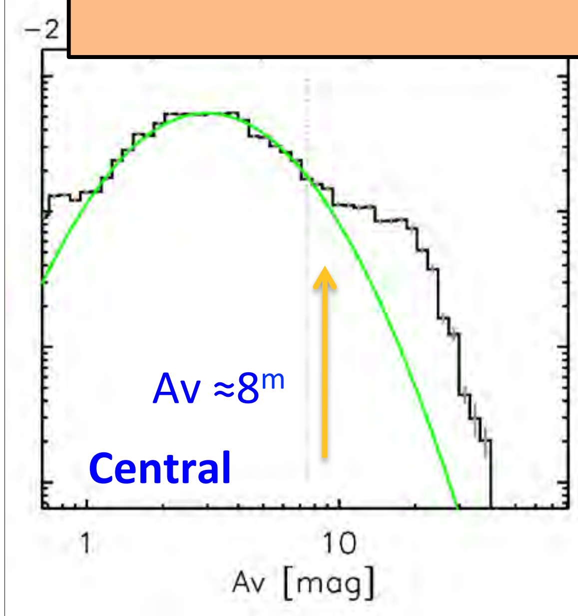


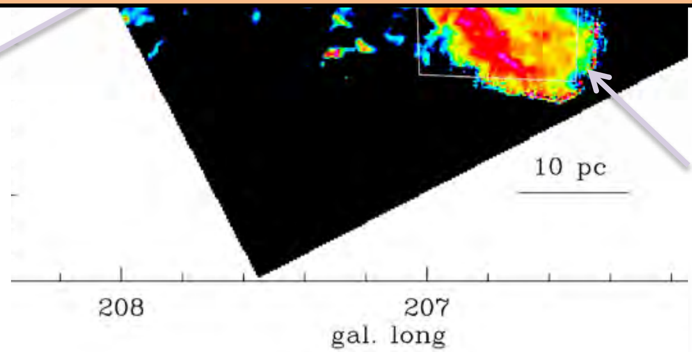

Column density map
Rosette

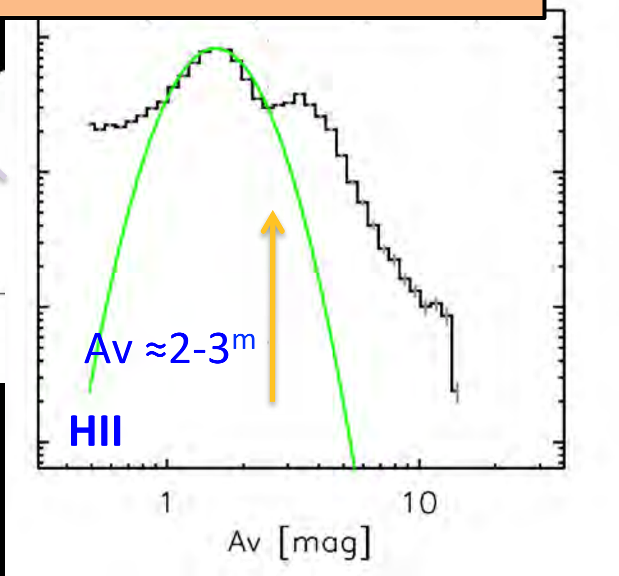


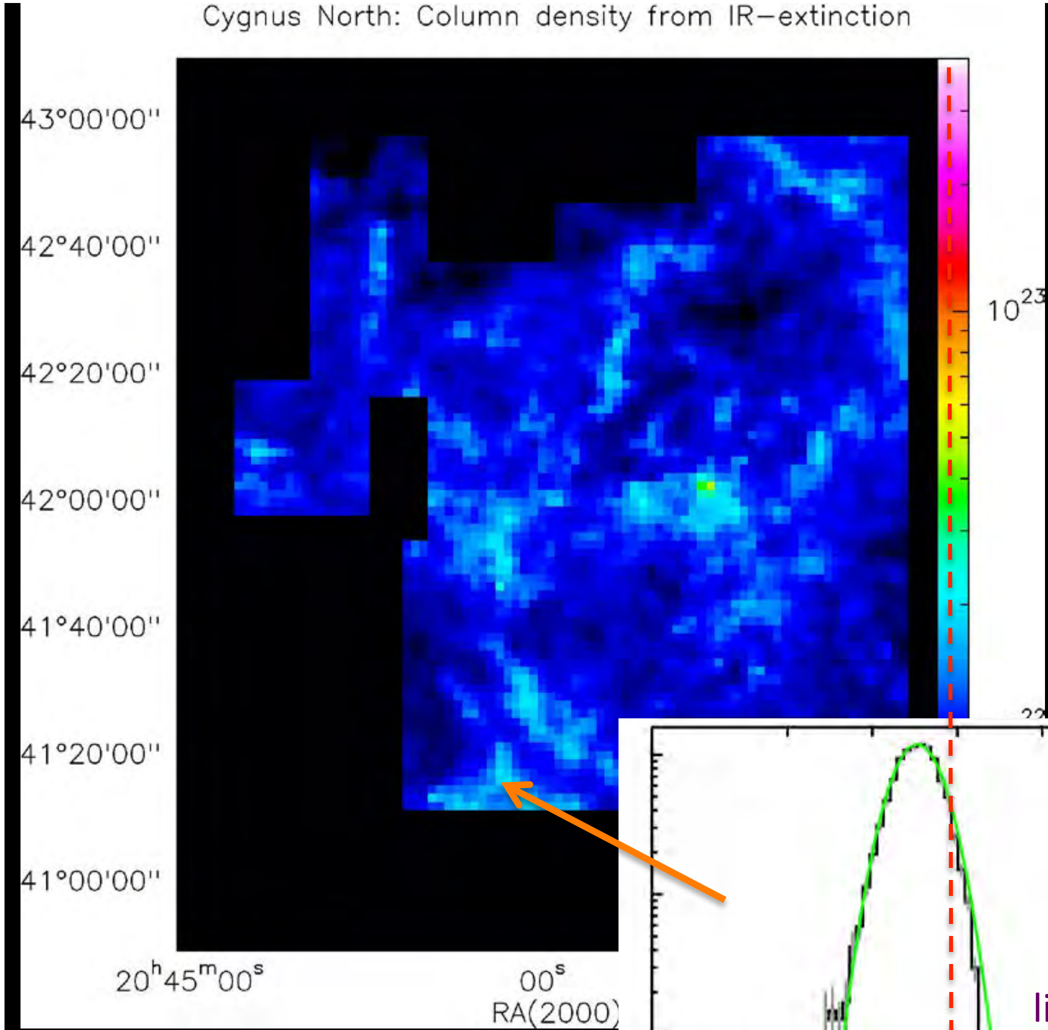

**There is *no significant difference* in the density structure of low- and high-mass star-forming molecular clouds.**

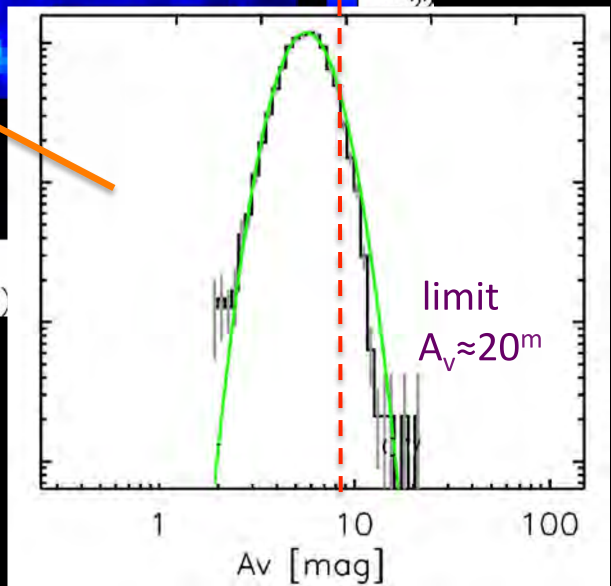



Schneider et al. 2010,
Schneider, Csengeri et al., in prep.




IR-extinction

120” resolution

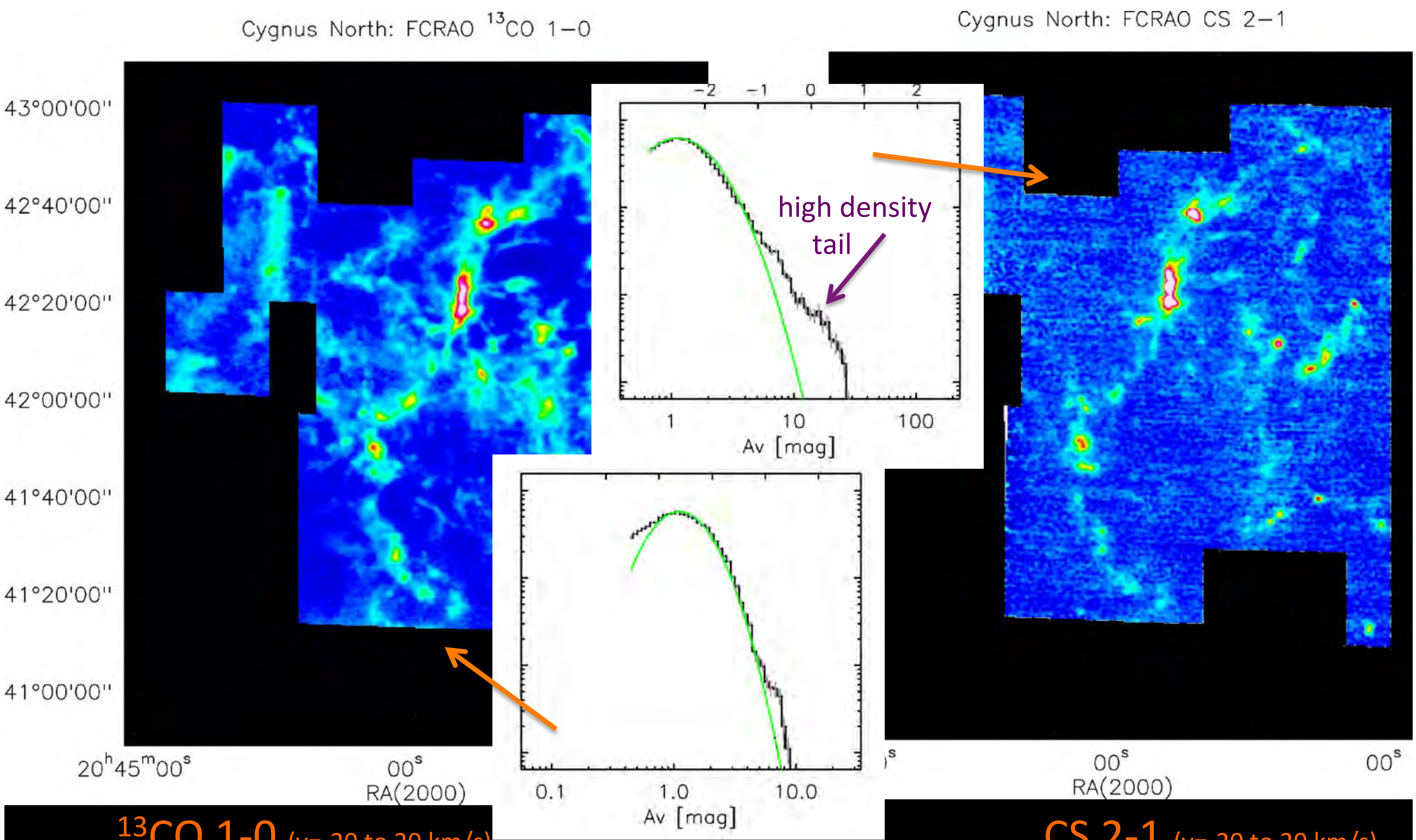
(Schneider et al. 2011, Bontemps et

Herschel

38” resolution

(Hennemann et al., in prep)

Probability Density Functions for Cygnus column density maps




$^{13}$CO 1-0 (v=-20 to 20 km/s)

45” resolution

(Schneider et al. 2010, 2011; Simon et al.)

CS 2-1 (v=-20 to 20 km/s)

48” resolution

Probability Density Functions for Cygnus molecular line maps

Problems (continuum and/or molecular lines):

- LOS confusion
- optical depth effects
- low angular resolution
- not enough dynamic range, in particular too much noise

To investigate the spatial and density molecular cloud structure we need:

- **sensitive**, **high angular resolution** maps of **optically thin** emission

-> **array heterodyne receiver** at low frequencies (up to 350 GHz) on a large summ-radiotelescope for large line surveys

-> mm-bolometer less useful because they filter out extended emission
Herschel (SPICA, JWST … ) are required

-> mm-bolometer are required for source detection